Spotting Hidden Sectors with Higgs Binoculars

Jennifer Thompson
02.10.2019

Higgs Couplings 2019
Oxford, UK

Motivation

• Higgs sector opens up new search options
  – Good place to look for new physics
• Introduce new particles coupled to Higgs sector
• Many mono-X searches
  – We consider HH+MET
• Future HL-LHC: 13 TeV, 3 ab⁻¹
  – Chance to find rarer processes

Existing HH+MET searches (SUSY)
arXiv:1709.04896 [hep-ex]
arXiv:1806.04030 [hep-ex]
Model Lagrangian and Details

Add 2 new scalars to the SM:

Effective coupling to visible sector (via B)

\[ \mathcal{L} \supset \frac{g}{\Lambda} B G_{\mu\nu}^a G^{\mu\nu a} + \frac{m_{BAA}}{2} B A A. \]

Decay to new scalars (A)

Add decays to SM particles and missing energy:

\[ \mathcal{L}_S \supset \lambda_{A\chi} H H A \chi H^\dagger H \]

\[ \mathcal{L}_R \supset m_{AHH} A H^\dagger H + \frac{m_{A\chi\chi}}{2} A \chi \chi. \]

symmetric

resonant

Missing Energy

UNDER INVESTIGATION
Model Lagrangian and Details

Add 2 new scalars to the SM:

\[ \mathcal{L} \supset \frac{C_{Bgg}}{\Lambda} B G^a_{\mu\nu} G^{\mu\nu} + \frac{m_{BAA}}{2} B A A. \]

Add decays to SM particles and missing energy:

\[ \mathcal{L}_S \supset \lambda_{A\chi} H H A \chi H^\dagger H \]

\[ \mathcal{L}_R \supset m_{AHH} A H^\dagger H + \frac{m_{Axx}}{2} A X X. \]

symmetric

resonant
Can $\chi$ be Dark Matter?

Stable: impose $\mathbb{Z}_2$ symmetry

$$\mathcal{L} = \frac{C_{Bgg}}{\Lambda} B g^\alpha G_{\mu\nu} G^{\mu\nu} + \frac{m_{BAA}}{2} B A A + m_{AHH} A H^\dagger H + \frac{m_{Axx}}{2} A_{XX} + \lambda_{A\chi HH} A \chi H^\dagger H. $$

h-\chi mixing after EW-breaking
- Set mixing angle = 0

h-A mixing after EW-breaking
- Strong DD bounds
- Here: relative size is important
- Set both $m_{AHH}$ and $m_{Axx}$ small

Thermal relic?

- $2M_\chi \approx M_H$
- $2M_\chi \approx M_H$
- $M_\chi > M_H$

Note: If unstable, $\chi$ could decay outside the detector
→ Could be detected by FASER, MATHUSLA
Signal Kinematics

- Kinematics driven by splitting
  - $M_B - 2M_A$, $M_A - (M_H + M_\chi)$
  - $M_B - 2M_A$, $\min(M_A - 2M_H, M_A - 2M_\chi)$

- MET harder in resonant
  - Aligned with parent A

Higgs boson $p_T$:
- Symmetric harder than resonant

Spans boosted to $\sim$resolved regime
Search Strategy

- Focus on HH decay to 4 $b$
- Background: V+jets, $t \bar{t}$
- Make use of signal features
  - Multiple b-jets
  - Large MET
  - No leptons
  - 2 Higgs boson resonances
- 200 GeV MET cut (triggering)
- 2 Higgs candidates:
  - 2 fat jets each b-tagged
  - Higgs mass window?
- Use a Boosted Decision Tree
**Resonant Model**

Cut flow based on signal features

More b-tags reduces significance

BDT input

- 2 fat jets (R=0.6)
- N, M b-tagged subjets

Higgs mass window hurts us
Resonant Model

Cut flow based on signal features

BDT gives much better sensitivity

More b-tags reduces significance

BDT input

- $E_T > 200$ GeV
- 1-1 btag
- 2-1 btag
- 2-2 btag
- HMW

N-M:
- 2 fat jets ($R=0.6$)
- N, M b-tagged subjets

Higgs mass window hurts us

$\sqrt{s} = 14$ TeV, $L = 3$ ab$^{-1}$

$R_{750,350,25}$

$\beta = 0$ (no syst.)
$\beta = 1$
$\beta = 5$
$\beta = 10$

AUC = 0.907

precision

true positive rate

false positive rate

recall

$S/\sqrt{S+B+(\beta B)^2}$

$S$
Symmetric model

Fat jets $R=1.2$

More b-tagged subjets

BDT input

Higgs mass window good for larger systematics
Discovery Cross Sections

**Symmetric**
- Smaller required cross section:
  - Larger $M_A$
  - Larger $M_B$
  - Larger $M_\chi$

**Resonant**
- $2M_\chi < M_A, M_\chi$ irrelevant
- Very small production rate

Could be visible at the HL-LHC

Not so visible at the HL-LHC
Conclusion

- Introduced 2 models with 3 new scalars
  - Couple to the Higgs sector
  - Lightest scalar is stable
  - Can be embedded into larger, complete models
- Symmetric model could be seen at HL-LHC
- Resonant model has a lower significance
  - Needs 2-10 larger cross section than our rate
- Can be a thermal relic in some parameter space